EFFECT OF NITRIDING ON FATIGUE LIFE OF THE CYLINDER BLOCK FOR TWO-STROKE ENGINE

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ABSTRACT

Aluminum alloys are one of the most capable material selections for automobiles parts and electrical component to reduce their weight and to increase their specific strength. This project report describes the role of nitriding process on fatigue life of the cylinder block for a two-stroke internal combustion engine. The objectives of this project are to predict the fatigue life of cylinder block using stress-life, to identify the critical location, toinvestigate the effect nitriding process and to optimize cylinder block's material. The structural model of cylinder block was developed using the computer aided design software. The finite element modeling and analysis were performed utilizing finite element analysis code. The set of aluminum alloys is consider in this study. The three-dimension solid model was imported to the MSC.PATRAN software and employed to generate meshes and define material properties for finite element modeling. The finite element analysis was performed using MSC.NATRAN code. The finite element model of component was analyzed using the linear elastic approach. The fatigue life analysis was carried out using MSC. FATIGUE software. Fatigue stress-life approach was used and sensitivity analysis on fatigue life is discussed. Stresses obtained previously are employed as input for the fatigue life. From the result, it was shown that the Goodman mean stress correction method is predicted more conservative (minimum life) results. It was found to differ considerably the compressive and tensile mean stresses to give noticeable advantages and fond to be design criteria. Based on the finite result, it is observed that the nitrided treatment produces longest life for all loading conditions. Therefore, the nitriding process is one of the promising surface treatments for aluminum alloy part to increase the fatigue life of the linear engine cylinder block.

ABSTRAK

Aloi aluminium merupakan bahan yang paling berkeupayaan dalam bidang pembuatan perkakas-perkakas elektrik dan dalam pembuatan bahan-bahan automotif yang bertujuan untuk mengurangkan berat bahan dan juga untuk meningkatkan daya kekuatan khususnye. Projek ini membentangkan penyelidikan menggunakan unsur terhingga berasaskan pengkomputeran tentang peranan rawatan permukaan terhadap hayat lesu dengan mengunakan rawatan nitrat bagi blok selinder terhadap komponen enjin linear omboh dua-lejang dalam enjin pembakaran. Objektif projek ini dijalankan ialah untuk meramalkan penilaian kebolehtahanan, untuk mengenalpasti komponen enjin linear omboh yang selamat, untuk menyiasat kesan rawatan nitrat dan untuk pengoptimuman bahan bagi silinder blok. Permodelan struktur pejal tiga-dimensi bagi enjin omboh dibangunkan dengan perisian lukisan bantuan komputer.Pengesahan model unsur dan analisis unsur dibangunkan untuk pengesahan keputusan kod model unsur. Set aloi aluminium digunaan dalam projek ini. Model pejal tiga- dimensi dimasukkan ke perisian MSC.PATRAN bagi menjana jejaring dan ditentukan sifat bagi permodelan unsur terhingga. Analisis unsur terhingga dijalankan dengan kod MSC.NASTRAN. Model unsur terhingga bagi komponen dianalisis menggunakan pendekatan elastik linear. Hayat lesu analisis diteruskan dengan menggunakkan perisian MSC. FATIGUE. Pendekatan tegasan hayat lesu digunakan dan kepekaan hayat lesu analisis dibincang. Tegasan yang diperolehi sebelumnya digunakan sebagai masukan dalam pengiraan hayat lesu. Keputusan didapati bahawa analisis menggunakan kaedah pembetul tegasan min Goodman meramalkan hayat konsevertif. Ia menunjukan perbezaan berdasarkan tegangan dan pemendekan tegasan min memberi kebaikan kepada reka bentuk kriteria. Berdasarkan keputusan yang diperolehi menunjukkan rawatan nitrat memberikan hayat lebih panjang untuk semua keadaan bebanan. Oleh itu, proses penitridan memberi rawatan permukaan yang baik bagi komponen aloi aluminium menambah hayat enjin silinder blok.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

N_i	Number of fatigue life
S_i	Load cycle with amplitude
D	Cumulative damage
n_i	Number of load cycles at this amplitude
S_r	Constant stress range
S_a	Constant stress amplitude
N_f	Fatigue life
S_m	Mean stress
R	Stress ratio
A	Amplitude ratio
σ_a	Stress amplitude
σ'_f	Fatigue coefficient,
b	fatigue strength exponent
S_e	Altering stress
σ_m	Mean stress
S_u	Ultimate tensile strength
σ_f	True tracture strength
S_f	Fatigue strength
n	Strain hardening exponent
K	Strength Coefficient
$K1C$	Fracture toughness
S_y	Yield Strength

LIST OF ABBREVIATIONS

AA	Aluminum Alloy
A-A	ASTM air to air typical fighter loading
Al	Aluminium
ASTM	American Society for Testing and Materials
CAD	Computer-Aided Drafting
CAE	Computer-Aided Engineering
DS	Double Strap
FEM	Finite Element Modeling
FE	Finite Element
IC	Internal Combustion
MBD	Multibody Dynamics
SAE	Society of Automotive Engineers
MPC	Multi-Point Constraints
AISI	Steel

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The most of the failure observed in the real structure and mechanical component are due to the fatigue. In the design of the real system subjected to the environment loadings, both the fatigue strength and dynamic properties of the external loads are important. Fatigues are the progressive and localize material damage that occurs when material is subjected to cyclic loading. Fatigue is an important parameter to be considered in the behavior of components subjected to constant and variable amplitude loading (Torres and Voorwald, 2002). In this study variable amplitude are consider due to the service load histories. Realistic representation of service load is a key ingredient of successes fatigue analysis. Therefore, it is important to accurate measure the applied load on existing component or structure or to predict loads on a component or structure does not yet exist. (Koster and Field, 1973) suggested that the main mechanical property adversely affected by machining is high cycle fatigue strength, the actual endurance limit being dependent on the particular process used and the severity of operation. While it is known that fatigue life is heavily influenced by residual stresses, the metallurgical condition of the materials and the presence of notch-like surface irregularities induced by machining play a key role (Novovic et al., 2004).

Cylinder block is the most critical component of engine in automotive industry. The cylinder block or engine block is a machined casting (or sometimes an assembly of modules) containing cylindrically bored holes for the pistons of a multi-cylinder reciprocating internal combustion engine, or for a similarly constructed device such as a pump. The engine cylinder block or "block" is cast in one piece. Usually, this is the largest and most intricate single piece of metal in the automobile. Even when the cylinders, cylinder heads, or cylinder sleeves are separate pieces, the crankcase is still the largest single part in the engine. The cylinder block serves as the main structural component of the engine and houses what's commonly referred to as the "the bottom end" (crankshaft, rods, pistons). Cylinder block structures are very commonly subjected to fatigue loading (Rahman et al., 2006a).

Aluminum (Al) and its alloy have benefit over non metallic materials: aluminum alloys have a high melting point, a good workability and also have a good thermal conductivity. Aluminum alloys are one of the most capable material selections for automobiles parts and electrical component to reduce their weight and to increase their specific strength (Rahman et al., 2007a). Aluminum alloys is suitable material due to safety, environmental and performance benefit.

Nitriding is now widely used in manufacturing for surface hardening of ferrous and non-ferrous materials. Nitriding, one of the most widely used thermo-chemical methods, produces a high compressive residual stresses on the surface of components. Nitriding is a process for hardening the surface by diffusing nitrogen into the surface. All machining, stress relieving, as well as hardening and tempering are normally carried out before nitriding. Nitriding steels offer many advantages: a much higher surface hardness is obtainable when compared with case-hardening steels; they are extremely resistant to abrasion and have high fatigue strength.

1.2 PROBLEM STATEMENT

Cylinder block is the critical component in the internal combustion engine. The cylinder block failure is due to the fatigue. Due to the market pressure for improvements in productivity, reliability, ductility, wear resistance and profitability of mechanical system, manufacturers replacing increasing demands on available materials (Rahman et al., 2006). Surface treatment likes nitriding is used to improve fatigue performance and increased the life. This simplification allows designers to use linear elastic stress results obtained from multibody dynamic FE (finite element) simulations for fatigue life analysis. To optimize component material, aluminum alloys is the suitable material due to light and less weight. Nowadays, the most capable material selection for automobiles parts and manufacturing is aluminum alloys because it light and less weight.

1.3 OBJECTIVES OF THE PROJECT

This project is focus on the finite element based on the fatigue analysis of the cylinder block for a two-stroke internal combustion engine using positive mean loadings.

The overall objectives of this project were:

(i) To predict the fatigue life of the cylinder block using stress-life method and to identify the critical locations
(ii) To investigate the effect of nitriding treatment
(iii) To optimize cylinder block's material

1.4 SCOPE OF STUDY

This project concentrates on the stress-life approach under variable amplitude loading. The scopes of study are as follows:

(i) Structural modeling
(ii) Finite element modeling (FEM)
(iii) Fatigue analysis
(iv) Surface treatment analysis
(v) Optimization of material

1.5 OVERVIEW OF THE REPORT

Chapter 1 gives the brief the content and background of the project. The problem statement, scope of study and objectives are also discussed in this chapter.

Chapter 2 discusses about the fatigue life prediction method, fatigue life prediction in variable amplitude loading and surface treatment process.

Chapter 3 presents the development of methodology, finite element modeling and analysis, fatigue life prediction technique and linear elastic analysis.

Chapter 4 discusses the result and discussion of the project. The discussion aims is to determine the predicted facts and correlate them with the current international researches on the field of the fatigue mean stress effects.

Chapter 5 presents the conclusions of the project. Suggestions and recommendations for the future work are put forward I this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to provide a review of the past research related to the surface treatment, fatigue life method and variable amplitude loading. The review is organized chronologically so as to offer approaching to how research hard works have laid the base for subsequent studies, including the present research effort. The review is fairly detailed so that the present research effort can be properly modified to add to the present body of literature as well as to justify the scope and direction of present research effort.

2.2 FATIGUE LIFE PREDICTION METHOD

Fatigue analysis can be used to determine how long the component can maintain in a given service condition. In general, fatigue life refers to the ability of a component to function in the presence of defect for a given loading. In practice, the predominant failure mode is fatigue and hence, the term fatigue life analysis was used to describe the analysis of the fatigue performance. In engineering design, the criteria for the fatigue life of a component can very depending of the functional requirements of material characteristic. The fatigue properties are determined from the constant amplitude loading test. However, the real structural seldom experience constant amplitude loading. Therefore, an irregular loading history must be reduced to a series of constant amplitude events each with its corresponding mean and amplitude for comparison with sample laboratory specimen testing data.

Rahman et al. (2007b) were studied about finite element based durability assessment in a two- stroke free piston linear engine component using variable amplitude loading. The study discussed the finite element analysis to predict the fatigue life and identify the critical locations of the component. The effect of mean stress on the fatigue life also investigated. The linear static finite element analysis was performed using MSC. NASTRAN finite element software. The result was capable of showing the contour plots of the fatigue life histogram and damage histogram at the most critical location.

Conle and Mousseau (1991) used vehicle simulation and the finite element result to generate the fatigue life contours for the chassis component using automotive proving ground load history result combine with the computational techniques. They concluded that the combination of the dynamics modeling, finite element analysis is the practical techniques for the fatigue design of the automotive component.

Srikantan et al. (2000) discussed vehicle durability and fatigue analysis using data from proving ground testing. The authors discuss the differences between yield strength based durability analysis and fatigue analysis. Fatigue analysis reduces the design cycle and produces a more optimally design structure. The authors concentrated on the design of the truck body structure and the service duty that accompany them. The loads from proving ground test of similar vehicle. The simulation used to calculate fatigue life is MSC.FATIGUE, while the stresses are determined using MSC.NASTRAN. When the fatigue life design criteria are met a prototype is then built and tested. If the design criteria are not met the prototype is modified. The results from a correlation study showed the analytical strains from FE analysis and proving ground test correlated very well.

Nadot and Denier (2003) have been studied fatigue phenomena for nodular cast iron automotive suspension arms. They find out that the major parameter influencing fatigue failure of casting components are casting defects. The high cycle fatigue behavior is controllers mainly by surface defects and oxides while the low cycle fatigue is governed by multiple cracks initiated independently from casting defects.

Kim et al. (2002) also studied a method for simulating vehicles dynamic loads, but they add durability assessment. For their multibody dynamics analysis (MDA) they use DADS and a flexible body model. The model was for a transit bus. For the dynamic stresses analysis MSC.NASTRAN was used. The fatigue life was then calculated using a local strain approach. From the fatigue life, it was found that the majority of the fatigue damaged occurred over a frequency range that depend on terrain traveled (service or accelerated test course). This showed that the actual service environment could be simulated instead of using an accelerated testing environment.

2.3 VARIABLE AMPLITUDE LOADING

When components are subjected to variable amplitude service loads, additional uncertainties arise, whether the loading in laboratory tests related to the loads that could be expected to appear. Traditionally this problem is solved by using the simplifying assumption of damage accumulation, and constant amplitude tests in laboratory are transformed to variable amplitude severity by the Palmgren-Miner rule which says that a

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$$D = \sum_{i=1}^{m} \frac{n_i}{N_i} \tag{2.1}$$

load cycle with amplitude S_i adds to the cumulative damage D, a quantity $(1/N_i)$. Here, N_i denotes the fatigue life under constant amplitude S_i loading with amplitude and ni is the number of load cycles at this amplitude. The lack of validity of this accumulation rule has been demonstrated in many applications and in consequence its usage will introduce uncertainties which must be compensated for by safety factors, see for instance (Berger et al., 2002).

One possible way to diminish the deviations from the damage accumulation rule is to perform the laboratory experiments closer to the service behavior with respect to the loads. A method for establishing a Wohler curve based on variable amplitude loads has recently been developed and is presented in a parallel paper (Johannesson et al., 2003).The use of this method should be customized to each specific application by performing laboratory tests with load spectra covering different service requirements. One idea is that service measurements are used to establish a few reference load spectra for use in laboratory tests. Based on the resulting variable amplitude Wohler curve, fatigue life can be predicted for load spectra similar to the reference types.

Svensson et al. (2004) were conducted the fatigue life prediction based on variable amplitude tests-specific applications. Three engineering components have been tested with both constant amplitude loading and with different load spectra and the results are analyzed by means of a new evaluation method. The method relies on the Palmgren-Miner hypothesis, but offers the opportunity to approve the hypothesis validity by narrowing the domain of its application in accordance with a specific situation. In the first case automotive spot weld components are tested with two different synthetic spectra and the result is extrapolated to new service spectra. In the second case, the fatigue properties of a rock drill component are analyzed both by constant amplitude tests and by spectrum tests and the two reference test sets are compared. In the third case, butt welded mild steel is analyzed with respect to different load level crossing properties and different irregularity factors.

Nolting et al. (2007) were investigated the effect of variable amplitude loading on the fatigue life and failure mode of adhesively bonded double strap (DS) joints made from clad and bare 2024-T3 aluminum. They concluded that the fatigue life of a variable amplitude loading spectra can be calculated with reasonable accuracy using an effective stress range vs. life fatigue curve. The effective stress range vs. failure life curve is dependent on the bond geometry and therefore this curve must be developed for component geometry of interest. The effective stress range vs. life fatigue curve should be used to predict the fatigue life of clad specimens if the failure mode of the clad specimens is expected to be adhesive failure (i.e., if the spectrum includes large overload cycles).

Molent et al. (2007) have been evaluated the spectrum fatigue crack growth using variable amplitude data. This paper summarizes a recent semi-empirical model that appears to be capable of producing more accurate fatigue life predictions using flight load spectra based on realistic in-service usage. The new model described here provides an alternative means for the interpretation of full-scale and coupon fatigue test data, and can also be used to make reliable life predictions for a range of situations. This is a very important capability, particularly where only a single full-scale fatigue test can be afforded and should lead to more economical utilization of airframes.

2.4 SURFACE TREATMENT

The surface treatment of a component is a common site for initiation of fatigue crack. Therefore, the manner in which in the surface is prepare during manufacturing of the components has a vital role in dictating the initiation life for the surface fatigue cracks. There exists a variety of surface treatment such as carburizing, nitriding, and flame hardening which is design to impart high strength, wear resistance or corrosion resistance locally in the near surface regions of the material.

Nitriding is often used high strength aluminum and titanium alloy to improve fatigue performance (Novovic et al., 2004; Bell et al., 1998). Nitriding is now widely used in manufacturing for surface hardening of ferrous and non-ferrous materials. Nitriding ia a well-known case hardening process in which nitrogen is introduced into the surface of a solid ferrous alloy by holding the alloy at a suitable temperature in contact with a nitrogenous gas (usually ammonia) or a liquid cyanide bath (ASM, 1991). The nitriding temperature for all steels is generally between 530 and 580^{0}C. The principle reasons for nitriding are:

(i) To obtain high surface hardness
(ii) To increase wear resistance and anti-galling properties

(iii) To improve fatigue life

(iv) To obtain a surface that is resist to the softening effects of heat at temperatures up to the nitriding temperature.

Although, at suitable temperature, all steels are capable of forming iron nitrides in the presence of nascent nitrogen, the nitriding results are more favorable in those steels containing one or more of the major nitride forming alloying elements. Unalloyed carbon steels are not suitable for nitriding as they form an extremely brittle case that spills readily and the hardness increase in the diffusion zone small. Of the alloying elements commonly used in commercial steels, aluminum, chromium, vanadium, and molybdenum are beneficial in nitriding as they form hard nitrides that are stable up to the nitriding temperature. Since aluminum is the strongest nitride former of the common alloying elements, aluminum-containing steels (0.85-1.25% Al) yield the best nitriding results in terms of total alloy content. Chromium-containing steels can approximate these results if their chromium content is high enough.

Farrahi and Ghadbeig (1995) carried out an investigation into the effect of various surface treatments on fatigue life of a tool steel. The effects of nitriding, nitrocarburizing and shot peening on fatigue behavior of AISI D3 cold work tool steel were investigated. They found out that nitriding and nitrocarburizing treatments may improve abrasive-wear resistance of this material by increasing surface hardness and the peening is the best treatment to improve the fatigue life of AISI D3 tool steel.

Karaoğlu (2002) conducted an investigation on the wear of plasma nitrided AISI 5140 low-alloy steel in relation to the effect of parameters such as temperature, time and nitrogen partial pressure. The work carried out by this author indicated that the case depth and compound layer thickness that are formed during nitriding increased with increasing process temperature and time and that, although the wear resistance improved considerably after the plasma nitriding, for achieving the maximum resistance to wear, process parameters should be chosen to minimize the compound layer thickness and maximize the surface hardness and case depth.

Hosmani et al. (2005) investigated the nitriding behavior of a Fe–7Cr alloy at 580 °C in a gas mixture of ammonia and hydrogen, when the nitriding potential was varied from 0.03 to 0.818 atm$^{-1/2}$. The nitrided zone in this material was observed to be composed of two different regions, one with finely dispersed small CrN continuous precipitates in α-Fe grains and another, near the surface, where the precipitates were observed to coarsen in a discontinuous manner leading to a lamellar CrN/α-Fe morphology. The maximum hardness in the nitrided zone and the nitriding depth were both observed to increase with increasing nitriding potential, as long as no iron nitride layer developed at the surface of the specimens. Also, the nitriding depth was observed to depend roughly linearly on the square root of the nitriding potential.

2.5 CONCLUSIONS

Different types of the fatigue life prediction method and durability assessment approach have been reviewed in this chapter in conjunction with surface treatment and variable amplitude. Many researchers have carried out their research based on the fatigue life, durability assessment, surface treatment and variable amplitude. Most of the methods available in literature reviews are used for the study. The next chapter will be concentrated on the methodology will be presented in the

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The fatigue life of engineering structure principally depends upon that of its critical structure members. There is an increasing within the internal combustion engine industry in the ability to produce design that safe, reliable, light in weight, economic and easy to produce. Nowadays, increasing demands in develop and deliver the reliable products in a timely manner necessary more testing to be coupled with the CAE procedures such as the finite element analysis and fatigue life analysis. In this chapter, the proposed fatigue analysis, stress-life method, structural modeling, material information and loading information are presented.

3.2 PROJECT FLOWCHART

Figure 3.1 shows the overall flowchart of the project

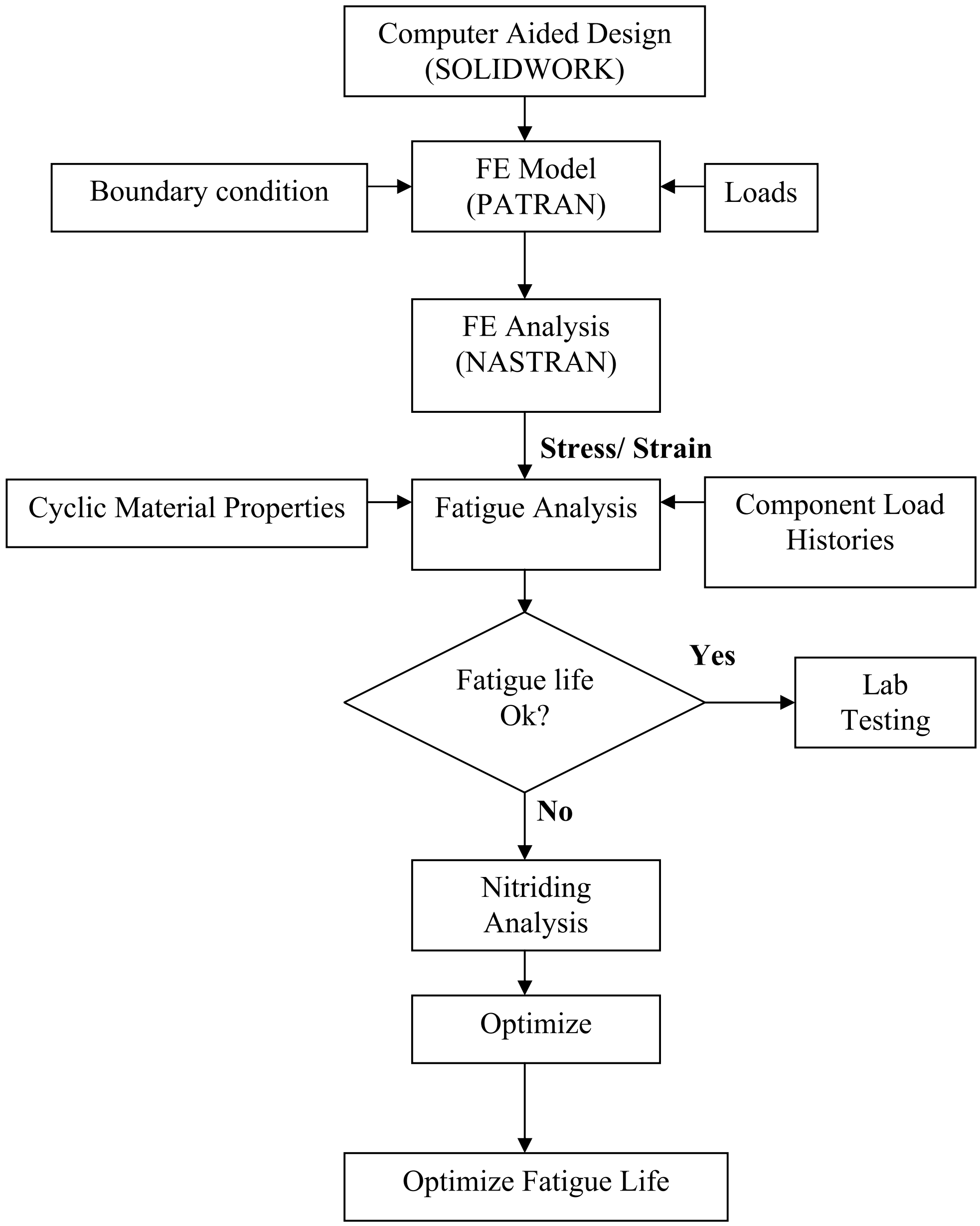

Figure 3.1: Flowchart of the project

3.3 STRUCTURAL MODELING

The Figure 3.2 shows 3D structural modeling of cylinder block in two different views. This structural modeling was developed using the computer aided design (SOLIDWORK) software.

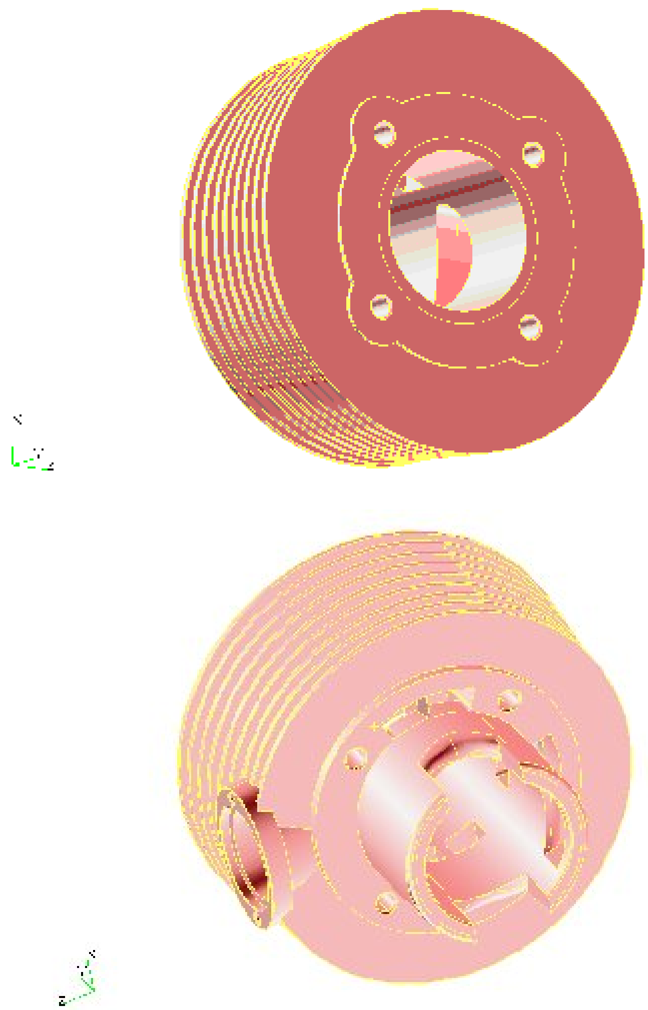

Figure 3.2: 3D structural modeling of the cylinder block (two different views)